Table 2. Respiratory rate depression by shell presence in pecans at greater than 6% field moisture.

Genotype	Shell wt. (kg) 30 nuts	Intact respiration rate/shelled respiration rate
Delmas	0.250	0.67
Stuart	0.236	0.76
Desirable	0.127	0.89
Mohawk	0.122	0.61
Moneymaker	0.113	0.68
Elliott	0.088	0.81
Chickasaw	0.087	0.78
Cheyenne	0.081	0.73
Shawnee	0.067	0.41

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Influence of Mycorrhizae and Drought Stress on Growth of *Poncirus* x *Citrus* Seedlings

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Abstract. **Roots of Carrizo citrange seedlings were inoculated with the vesicular-arbuscular mycorrhizal (VAM) fungus *Glomus intraradices* or provided an inoculum filtrate (non-VAM plants). Plants were exposed to drought stress after transplanting into large containers filled with a phosphorus amended medium (30 mg g^{-1}). Drought stress caused reduction of phosphorus in leaf tissues and dry matter accumulation in VAM plants. However, phosphorus levels, dry weights, and transpiration of VAM seedlings were greater than non-VAM plants. Mychorrhizal infection appears to improve establishment of citrus into transplant situations by improving phosphorus uptake and reducing plant stress.**

Establishment of nursery grown plants into landscape soils is often poor because of drought and nutrient stress. Nurserymen commonly apply luxuriant levels of water and nutrients to container plants to achieve rapid growth, but the root systems of such plants often are underdeveloped resulting in poor establishment in landscape sites (7).

Vesicular-arbuscular mycorrhizal (VAM) fungi enhance growth and development of many plant species (5, 11), and their role in plant nutrition (11, 16) and water relations (8, 12, 13, 15) has been well documented. Researchers have demonstrated improved adaptation of VAM colonized plants in field soils and attributed this response to reduced water stress (8, 10). Mycorrhizae may improve water uptake by increasing exploration of soil volume (15), improving plant nutrition (12, 6), and/or regulating stomates through hormone synthesis (1, 2, 9).

Objectives were to determine the role of VAM on growth, phosphorus nutrition and water relations of citrus seedlings after transplanting into a water stressed medium.

Carrizo citrange [*Poncirus trifoliata* (L.) Raf. x C. *sinensis* (L.) Osbeck] were transplanted at the 3 leaf stage into 100 ml containers filled with a 1 Canadian peat:1 fired montmorillonite clay (v/v) medium having 7 mg kg^{-1} available phosphorus (bicarbonate solution analysis). The medium was amended with superphosphate (8.7% phosphorus) and STEM (Soluble Trace Element Mix manufactured by W.R. Grace and Co., Cambridge, Mass., USA) at 0.50 and 0.25 kgM^{-3}, respectively. Half the plants were inoculated with the mycorrhizal fungus, *Glomus intraradices* Schenck and Smith, using a mixture of chlamydospores (100 spores g^{-1} soil), hyphae, and colonized roots. An inoculum filtrate was applied to the roots of non-VAM plants. VAM plants were fertilized weekly with 40 mg N per ml container from 25-0-25 (17.8% NH_4^+, 7.2% NO_3^-; 21.0% potassium) and non-VAM plants at the same rate of nitrogen from 20-20-20 (14.7% NH_4^+, 5.3%NO_3^-; 8.8% phosophorus; 16.6% potassium) solution. Plants were grown in a glasshouse with maximum daylight irradiance of 970 μmol $s^{-1}m^{-2}$ at 400-700 nm, and temperature was maintained at 30°C day and 21° night. These seedlings were transplanted after 6 weeks into 2.7 liter containers filled with amended medium described previously. Root colonization by *G. intraradices* was determined at transplanting using clearing and staining procedures described by Phillips and Hayman (14).

Plants were subjected to 2 irrigation regimes during the remainder of the experiment. Irrigation regimes were designated as nonstressed (10% weight loss of container capacity) and stressed (20% weight loss of container capacity). Container weights were established after 16 hr of drainage following each irrigation and weighed daily until 10% or 20% weight loss before reirrigation. Plants were fertilized with surface applied Osmocote (18.0% N–6.2% P–15.6%K) at a rate of 10 g per 2.7 l container every 3 months after transplanting. A randomized block design was used with 10 replicates and 1 plant per experimental unit.

Transpiration was determined after 6

Table 1. Influence of vesicular-arbuscular mycorrhizae (VAM) and soil moisture stress on percentage root colonization and P levels in leaves of Carrizo citrange seedlings.

Treatment		P (% dry wt)		Root colonization (%)	
VAM	Soil moisture[z]	At transplant	At termination	At transplant	At termination
−		0.096 a[y]		0	
+		0.105 a		36	
−	Stress		0.108 a		0
−	Nonstress		0.128 b		0
+	Stress		0.157 c		65
+	Nonstress		0.178 d		72

[z]Nonstress (10% weight loss of container capacity) and stressed (20% weight loss of container capacity).
[y]Mean separation within columns by Duncan's multiple range test, 1% level.

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Table 2. Influence of vesicular-arbuscular mycorrhizae (VAM) and soil moisture stress on growth and transpiration of Carrizo citrange seedlings.

Treatment		Leaf area	Leaf dry wt	Stem dry wt	Root dry wt	Transpiration	
						Total water loss per plant	Water loss per unit leaf area
VAM	Soil moisture[z]	(cm^2)	(g)	(g)	(g)	(g day^{-1})	(g $cm^{-2}day^{-1}$
−	Stress	70 a[y]	0.35 a	0.24 a	0.87 a	9.0 a	0.13 a
−	Nonstress	86 b	0.32 a	0.38 a	0.98 a	10.8 a	0.13 a
+	Stress	138 c	0.81 b	0.67 b	1.13 b	18.1 b	0.13 a
+	Nonstress	197 d	1.03 c	1.12 c	1.82 c	28.2 c	0.14 b

[z]Nonstress (10% weight loss of container capacity) and stressed (20% weight loss of container capacity).
[y]Mean separation within columns by Duncan's multiple range test, 1% level.

months at experiment termination by enclosing the container (medium at container capacity) in a plastic bag and determining weight loss after 24 hr. Leaf area, shoot and root dry weights, phosphorus analyses (vanadate molybdate-yellow procedure) and root infection also were determined.

Mycorrhizal colonization at transplanting was 36% and increased at experiment termination to 65% and 72% at 20% and 10% drought stress levels, respectively (Table 1). Similarly, Nelsen and Safir (12) noted little change in colonization of drought stressed onion plants, although spore production was considerably reduced. Phosphorus levels in leaf tissues of VAM and non-VAM plants were similar at the time of transplanting (Table 1). However, the phosphorus levels in the transplant medium appeared insufficient for uptake by non-VAM plants as indicated by P leaf tissue levels in comparison to VAM plants. Drought stress resulted in reduction of phosphorus uptake in both VAM and non-VAM plants. Bolgiano et al. (4) noted a decrease of P mobility in dry soils and consequent reduced availability to onion plants. Leaf areas were smaller in both VAM and non-VAM citrus as a result of drought stress (Table 2). However, leaf areas were twice as large for VAM compared to non-VAM plants at both levels of stress. Drought stress had little effect on other growth parameters of non-VAM plants, which may be related to low P levels in tissue and inhibition of plant growth regardless of drought stress. On the other hand, dry weight of leaves, stems, and roots of VAM plants were greater for 10% compared to 20% moisture stress. Imposition of drought stress on plants with adequate levels of nutrition has been shown to inhibit plant development, primarily as a result of stomatal closure and subsequent reduction in photosynthesis (3, 16).

Total water loss per plant was less for non-VAM compared to VAM citrus seedlings. Drought stress treatments had little influence on total water loss from non-VAM plants; however, water loss was increased in VAM plants receiving the nonstress treatment. Transpiration (g cm^{-2} leaf area day^{-1}) was similar to total water loss with nonstress, VAM plants showing the highest rate of loss. Increased transpiration rates of VAM citrus would be expected, with increased metabolic activity associated with VAM colonization (3, 5),

Results indicate that VAM seedlings can adapt to transplant conditions of drought stress and low to moderate phosphorus availability better than equivalent non-VAM seedlings. Other research has indicated improved adaptation of VAM plants into field soils, primarily attributed to reduced water stress (8, 10). In addition, increased water transport of mycorrhizal citrus plants under well irrigated conditions has been attributed to improved P nutrition (6). Our research confirms that phosphorus levels associated with VAM colonization also is a key to the positive growth responses observed in drought stress situations compared to non-VAM plants.

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